Study of Maize Drying in Uganda Using an in-Store Dryer Weather Data Simulation Software

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Abstract: The applicability of an in-store drying system in Uganda as an alternative for maize drying and storage was studied. With the 13.5 tonne capacity In-store Dryer (ISD) used in this study, the predicteddrying rates were lower,and investment costs and operating costs lower, than other comparable grain dryers. In the simulation, the fan and burner were operated 24 hours continuously irrespective of weather. Under these conditions for the two districts Jinja and Kasese, the cost of drying a kilogram of maize was estimated at around US$0.203/kg. The final product after drying had a dry matter loss (DML) of under 0.6% (Jinja0.45% and Kasese0.55%), indicating a high quality maize.

The profit margin, based on the current price of maize in Uganda of US$0.0507/kg, was better for the Kasese district. It was observed that both drying costs and profit were greatly affected by price fluctuations of fuel and electricity and also the unpredictable prices for maize.

Keywords: Drying, Moisture content, Maize, Uganda.

1. INTRODUCTION

Maize (*Zea mays* L) is one of the world's important cereal crops and a major staple food in Uganda [14, 24, 25]. The crop provides over 40% of the calories consumed per capita in both rural and urban areas [2]. Maize is produced over an area estimated at 844,000 hectares (ha) with a total production of 2,748,000 MT [6]. According to the Uganda Export Promotion Board (UEPB) the estimated earnings from maize exports on average generate over US$ 18.5 million in export earnings from about 66,700 tonnes exported per annum.

Drying is one of the most common and important ways of preventing post-harvest losses during grain handling [1, 4, 17]. In Uganda, the common practice for drying involves spreading the crop on bare ground, which takes up to a week to dry the late harvested cobs and over two weeks to dry a timely harvested crop under the open sun drying method [9, 13, 19]. Studies have shown that under these conditions, Maize is exposed to a proliferation of fungi, moulds and bacteria and soil, thereby reducing the quality of Maize [2, 10, 11].

The main purpose of drying is to reduce the water activity contained in the crop from the harvest level to a safe storage level, hence allowing a longer storage time with little deterioration [5, 12, 23]. Final quality of grains depends on a number of factors namely: harvesting conditions, drying, storage, early stages of postharvest operations and the environmental conditions during growth [4, 7]. With traditional methods mainly relying on natural air and the open sun, it is difficult to attain these levels. One of the main problems in Uganda is that the harvesting season coincides with the rainy season, leading to high air relative humidities which reduce the drying effect. This, when combined with the problem of poor storage facilities, affects the quality of maize. Moisture contents of harvested maize range from 18% - 25% wet basis (w.b.) [16]. For safe and long-term storage, moisture content levels should be reduced by drying to typically about 13.5% w.b. [18, 27].

In industrial countries like Australia and China, near ambient temperature drying systems have been applied for grain drying and storage [5]. In-store drying is widely accepted as an energy-efficient and gentle system. Maize drying is often done in in-store dryers because of their simplicity. Unfortunately, these dryers are hard to optimize due to the heterogeneity of the air and grain temperature and moisture content during the drying process. Grains are dried in bulk inside a bin where air is supplied from the bottom of a perforated surface to lower the moisture content to 14% w.b. Supplemental heating can be included in the system where necessary. In-store dryers (In-bin dryers or deep-bed dryers) are dryers that can be used to dry and also store farm produce [5, 21]. These dryers have

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been used by North Central region maize farmers in the USA since the 1950s usually on a trial-and-error basis, leading to spoilage of grain when low airflow rates and very high temperatures were used [20]. Equipment should be designed in order to prevent physical changes in the grains, preserve product quality, and maximize dryer efficiency [3, 26]. Substantial work has been done in the development of deep-bed drying models to study grain's thermal properties and the simulation of different drying processes and dryer types [8, 15, 26].

This study therefore examined the applicability of in-store drying systems in Uganda as an alternative for maize drying and storage. The results from the economic analysis of the ISD's in the two districts (Jinja and Kasese) were then analysed comparing energy consumption, drying time, drying costs, profit generated and the quality of the maize.

2. MATERIALS AND METHODS

2.1. Weather Data Modelling

The weather data was generated using the temperature and relative humidity of two different years 2008 and 2009. Weather data was obtained from the Uganda National Meteorological Authority (UNMA). Two districts; Jinja and Kasese from the eastern and western parts of Uganda respectively were used to study the applicability of the in-store dryer. These two districts exhibit a bimodal rainy season with two harvesting seasons, the first from June to August and the second from November to January. The existing weather records consist of the average maximum and minimum temperatures and relative humidity for each day of the month. This data was converted to an hourly basis using a trigonometric weather model, and saved as an input file for the "ISDryer" program which simulates the dryer. The required hourly temperatures for the "ISDryer" simulation program were derived using the following models.

2.1.1. Hourly Temperature

The daily minimum and maximum temperature values for the two districts were required for weather data generation. When mean monthly maximum temperatures were plotted, they followed a periodic flow. This meant that temperature could be modelled using cosine function. Hence, cosine curves were used to model the temperature in this study. Cosine functions were used to fit the temperature data (maximum and minimum daily values) over a cosine curve. The general model (equation 2.1) below was used;

$$\mathrm{T} = \mathrm{a}\cos \mathrm{bt} + \mathrm{c} \tag{2.1}$$

The time period for a day is 24 hours:

$$\frac{2\pi}{|\mathrm{b}|} = 24 \text{ hours, so } \mathrm{b} = {}^{\pi}/_{12}, 360° \text{ in radians } 2\pi$$

$$\text{Amplitude: } \mathrm{a} = -\frac{\mathrm{T_{max}} - \mathrm{T_{min}}}{2} \tag{2.2}$$

Assuming a maximum at 12 am gives:

$$\text{the principal axis, } \mathrm{c} = \frac{\mathrm{T_{max}} + \mathrm{T_{min}}}{2} \tag{2.3}$$

The equations used to estimate the hourly distribution from the given daily temperatures were developed for temperatures recorded at 9 hours (T_9) and at 21 hours (T_{21}) for each day of the month, converted to the actual maximum and minimum temperatures T_{min} and T_{max}. Inserting constants a, b and c:

$$\mathrm{T_t} = \frac{(\mathrm{T_{max}} + \mathrm{T_{min}})}{2} - \left[\frac{(\mathrm{T_{max}} - \mathrm{T_{min}})}{2} \cdot \cos\left(\frac{\pi \cdot \mathrm{t}}{12}\right)\right] \tag{2.4}$$

Evaluating at 9 am and 9 pm:

$$\mathrm{T_9} = \frac{(\mathrm{T_{max}} + \mathrm{T_{min}})}{2} - \frac{(\mathrm{T_{max}} + \mathrm{T_{min}})}{2} \cos\left[\frac{\pi \times 9}{12}\right] \tag{2.5}$$

$$\mathrm{T_{21}} = \frac{(\mathrm{T_{max}} + \mathrm{T_{min}})}{2} - \frac{(\mathrm{T_{max}} + \mathrm{T_{min}})}{2} \cos\left[\frac{\pi \times 21}{12}\right] \tag{2.6}$$

Simplifying and solving for T_{min} and T_{max}:

$$T_{max} = 0.8536 \times T_9 - 0.1464 \times T_{21} \tag{2.7}$$

$$T_{min} = 0.1464 \times T_9 + 0.8536 \times T_{21} \tag{2.8}$$

Where t is the hour at which the temperature is being calculated (hr). A similar procedure was used for calculating relative humidities at hourly intervals.

2.2. Drying Simulations

A computer simulation program called "ISDryer" which was developed by Driscoll and Srzednicki (Food Science and Technology Group, School of Chemical Sciences and Engineering, UNSW) as part of the project funded by the ACIAR Post-Harvest Program, is a set of programs covering aeration, storage and drying, was used for this study [22]. The latest version of this program is version 7.41 (last modified 10/12/2010) developed in June 2006. This program was used to simulate the drying conditions of maize grain in an in-store dryer under the typical weather conditions of some parts of Uganda. Simulations were run using the weather data from Jinja and Kasese districts from the eastern and western parts of Uganda respectively.

During the simulations, drying strategies allow different methods for drying to be tested, for example using continuous drying until the top layer of the grain reached the desired final moisture content of 14% w.b., or selecting only air with a strong drying effect. One of the selection parameters of the dryer was the top to bottom moisture difference (TBMD). Strategies enable us to reduce the moisture gradient in the grain bed. The main dryer simulation outputs are the average moisture content, average temperature of grain, drying time, heat energy, electric fan energy, top to bottom moisture difference and dry matter losses (DML).

2.3. Drying Costs

2.3.1. Fixed and Capital Costs

The drying system which includes all the components of the dryer, that is; the storage bin, fan, burner, and all other electrical and electronic components; was estimated to determine the total investment cost. The annual ownership cost was estimated at 16% of the dryer purchase price. But to determine the actual ownership/capital cost, we needed to start by estimating the depreciation rate at 10%, 8% interest on average investment, 0.5% for insurance and 3% for any possible repairs/maintenance on the dryer.

2.3.2. Total Drying Cost

Total drying cost was taken as the sum of the energy cost (fan and burner), labour cost, capital and fixed cost. The time of actual drying of the grains and also time taken to unload and load the dryer fraction of the harvest were included in the determination of the operating cost as seen in equation 2.13 and 2.14 below.

$$\mathrm{OC} = (\mathrm{EL}\cdot\mathrm{EU}\cdot\mathrm{n_{runs}}) + (\mathrm{LP}\cdot\mathrm{GU}\cdot\mathrm{n_{runs}}) + (\mathrm{n_{lab}}\cdot\mathrm{t_{run}}\cdot\mathrm{WL}\cdot\mathrm{TD}\cdot\mathrm{n_{runs}}) \quad (2.13)$$

$$\mathrm{n_{runs}} = \frac{\text{harvest length in hours}}{\mathrm{t_{dry}} + \mathrm{t_{loading}} + \mathrm{t_{unloading}}} \quad (2.14)$$

$$\text{therefore, the total drying} = \mathrm{FCC} + \mathrm{OC}$$

Where;

FCC is the Total Fixed and Capital Cost in US\$; OC is the operating cost/cost of drying; *EL* is the cost of electricity per kWhr for the fan (US\$/kWhr); *EU* is the number of kilowatt hours used by fan per run (kWhrs); n_{runs} is the number of runs per harvest; t_{dry} is time taken to dry the maize (actual time maize is in the dryer); $t_{loading}$ time for loading the dryer; $t_{unloading}$ is time for unloading the dryer; *LP* is the number of kilowatt hours used by the burner per run (kWhrs); *GU* is the cost of fuel per kWhr (US\$/kWhr); n_{lab} is the number of labourers needed at a time; t_{run} is time the dryer runs (hrs); *WL* is the hourly wage rate (US\$/hr) and; *TD* is the percentage of time spent on the dryer (%).

2.3.3. Profit

Penalty for poor quality grain was calculated using the formula below (2.18). The DML was considered as the main factor in this derivation for quality of the grain.

$$\text{Penalty} = \frac{\mathrm{DML}}{100} \times \mathrm{W_p} \times \mathrm{P_{maize}} \times \mathrm{n_{runs}} \quad (2.15)$$

The price difference after subtracting the purchasing cost/price for the wet maize was used to calculate the profit (C_p) as below.

$$\mathrm{P_{maize}} = {(\text{selling price} - \text{purchase price})}\big/{\mathrm{W_p}} \quad (2.16)$$

Where;

$$\text{purchase price} = \mathrm{C_{wet\,Maize}} \times \mathrm{M_w} \quad (2.17)$$

$$\text{selling price} = \mathrm{C_{maize}} \times \mathrm{W_p} \times (1 - \mathrm{DML\%}) \quad (2.18)$$

Therefore, the profit will be calculated using equation (2.19);

$$\mathrm{C_p} = \mathrm{C_{maize}} - \left[\frac{(\mathrm{FCC} + \mathrm{OC})}{\mathrm{W_p} \times \mathrm{n_{runs}}}\right] - \left(\frac{\text{Penalty}}{\mathrm{W_p} \times \mathrm{n_{runs}}}\right) \quad (2.19)$$

Where;

C_p is the profit per kg of dry maize (US\$); *DML* is the dry matter losses (%); W_p is the final weight of dried maize (kg); P_{maize} is the difference selling price and purchase price per kg of dry maize (US\$/kg); $C_{wetmaize}$ is the price of wet Maize at farm (US\$); M_w is the initial weight of wet Maize loaded into dryer (kg) and; C_{maize} is the price of dry maize per kilogram by the wholesalers (US$/kg).

3. RESULTS AND DISCUSSION

3.1. Weather Data for Jinja and Kasese Districts

The wettest days of the year 2008 were observed to be between day 100 and day 300 of the year, which were the months from March to May. The hottest months were from December/February and June/July. The average highest and lowest temperatures recorded for Jinja district for the year 2008 were 28.7°C and 17.5°C respectively. The relative humidity was in the range from 61.9% to 83.4% recorded. The weather data for the years 2008 and 2009 showed no significant differences within the wettest and driest months and for this reason the year 2008 data was used for the dryer simulation. Figure **1** below shows the relative humidity data for Jinja and Kasese districts in 2008 for the first harvest season of June/August.

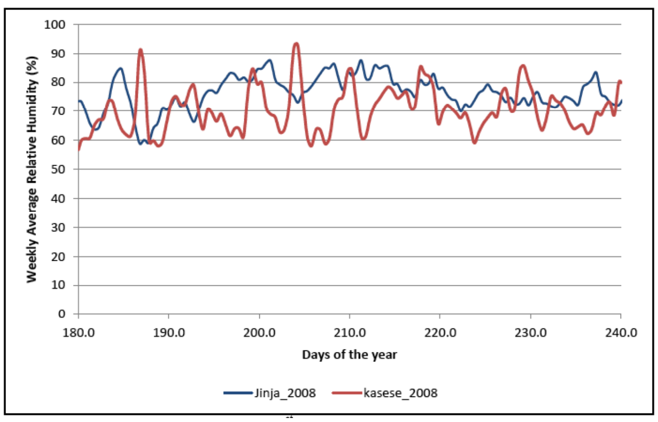

Figure 1: Relative Humidity for the 1st Harvesting Season for jinja and Kasese in 2008.

3.2. Simulation for Jinja District: Time-Clock Aeration Strategy

The Figures **2**, **3**, **4** and **5** below, show the different outputs of the in-store dryer simulation for the different bed depth and initial grain moisture contents at 10m/min air speed [16]. When choosing the best operating optimum conditions, the dry matter loss (DML) and the drying rate were considered as the main factors in optimising the dryer for best drying of maize. Simulations were carried out with different run conditions; (i) Air speeds (u_s) of 8, 10 and 12 m/min; (ii) Bed heights (H) of 4, 5 and 6 m; and (iii) Initial moisture contents (m_i) of 19, 21 and 23 % (w.b.). It was also assumed that drying should be completed within a maximum of two weeks (336 hours) from the time the maize is in the dryer. The drying runs were set to stop when the top layer moisture content reached 14% (wb). Operation of the fan and burner was continuous for 24 hours in order to achieve fast drying times.

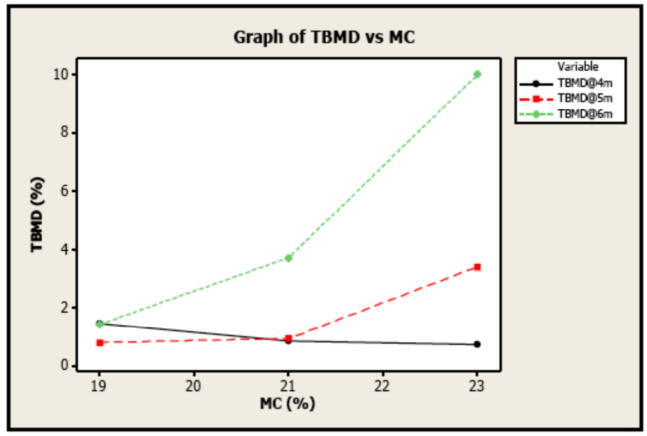

Figure 2: Graph of TBMD vs MC.

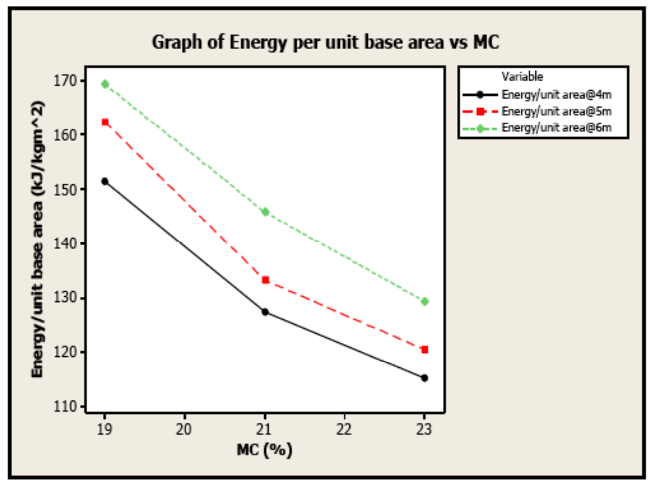

Figure 3: Graph of Energy per unit base area vs MC.

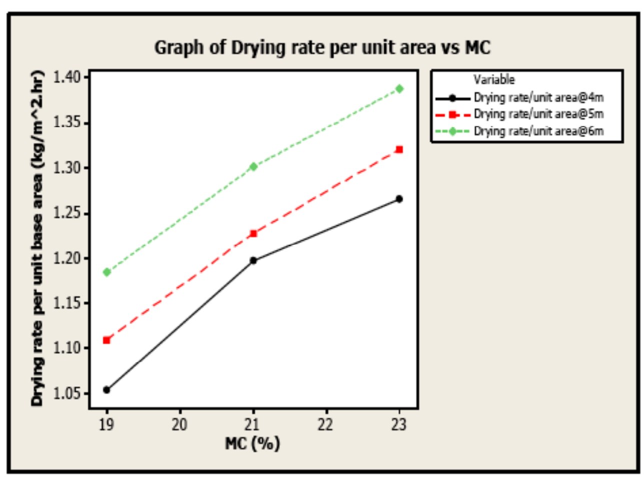

Figure 4: Graph of drying rate per unit base area vs MC.

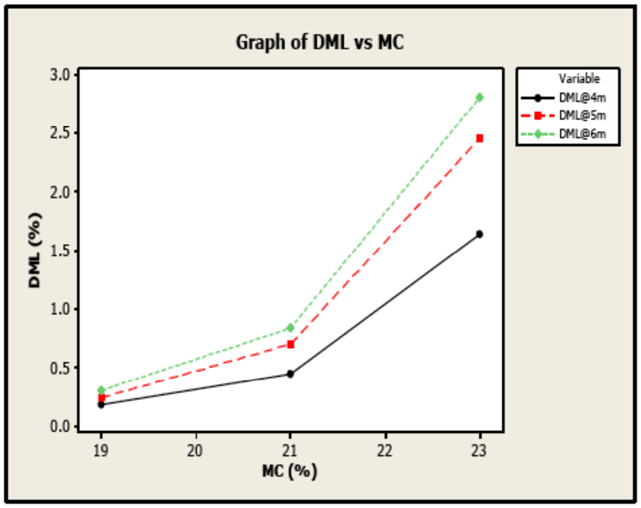

Figure 5: Graph of DML vs MC.

Quality is the major determinant for optimising the dryer. The parameters were weighted on a scale of 1 to 10 according to importance. DML and TBMD, being of highest importance for an efficient drying process and good quality maize were weighted at 9 and 7 respectively. Drying rate and energy consumption are less critical in practise, so were both weighted at 6.

To hunt for the optimum solution, an average harvest day was defined as day 210 of the year with air speed, fill height and initial moisture contents set to 10 m/min, 4 m and 21% respectively. The effect of air speed and bed depth/fill height on the final dry matter loss (DML) of maize dried at full operation of fan and burner was used as major variables for choosing the best drying parameters.

The simulation predictions agreed with common sense expectations of a grain drying bin. For example, it was observed from the simulation that as initial maize moisture content increased, drying rate increased but so did DML, showing a decrease in quality (Figure **2**, **3**, **4** and **5**).At low moistures, air is less able to pick up moisture from the product surface, and the air is used less efficiently. The DML also increased with fill height.

The best overall weighted solution was found to be 21% initial moisture content at a grain fill height of 4 m, with a moderately high drying rate of 1.27kg/hr.m^2, energy consumption per moisture extracted per unit area of 127kJ/kg.m^2, TBMD of 0.85% and DML of 0.45%.The variations of the different outputs from the simulations were also compared with the different air speeds as seen in Figures **6**, **7**, **8** and **9** below. It was observed that the fill height of 4 m and air speed of 10 m/min gave acceptable simulation outputs for DML, TBMD, drying rate and energy consumption.

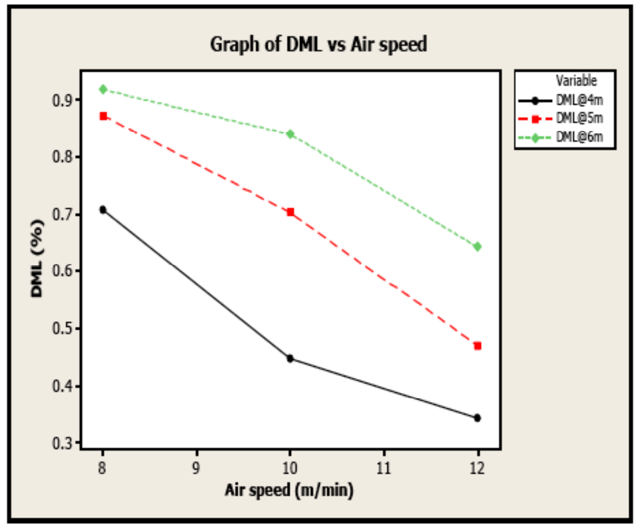

Figure 6: Graph of DML vs Air speed at 21% MC.

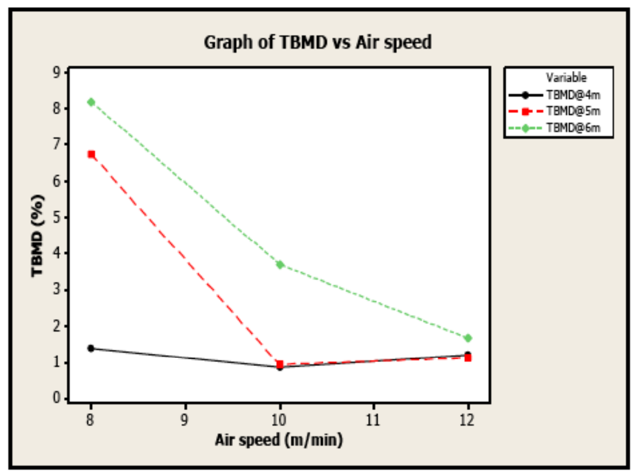

Figure 7: Graph of TBMD vs Air speed at 21% MC.

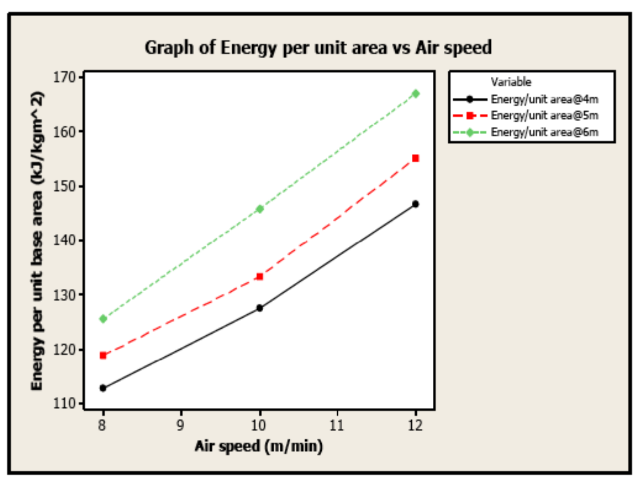

Figure 8: Graph of energy per unit base area vs Air speed at 21% MC.

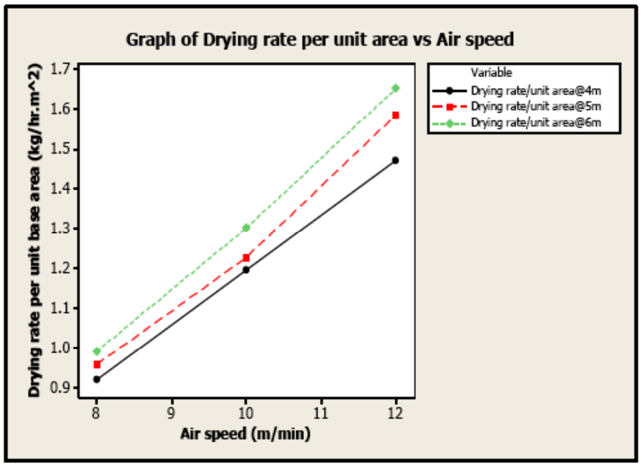

Figure 9: Graph of drying rate per unit base area vs Air speed at 21% MC.

An example of the moisture flow output using the 'ISDryer' program through bed of grain on day 210 for the year 2008 is seen above (Figure **10**). The simulation runs stopped when the moisture content for the top layer reached 14% (w.b.).

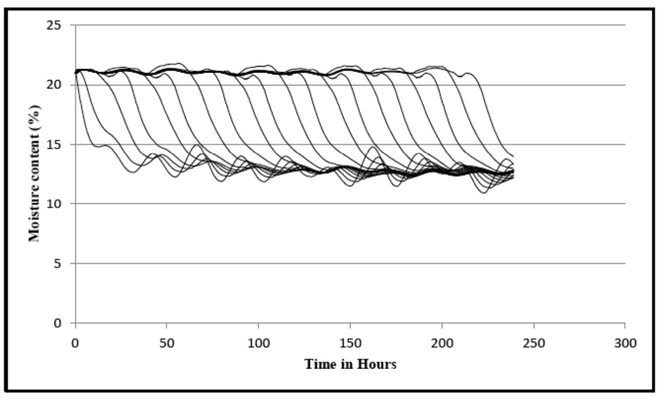

Figure 10: Plot for Moisture Content across the ISD using the Average Harvest Day.

Time clock strategies allow the fan and burner to be switched on or off according to the time of day. For example, early morning air might be too humid to have a drying effect. Various time clock strategies were tested: the fan and burner were switched off for 2 hrs, 4 hrs and 5 hrs from 23.00 hrs (11pm) to observe the effect on grain quality and the drying time.

Time clock strategies were not found to be effective, and were observed to cause longer drying times, lower drying rates, higher energy consumption per kilogram of moisture extracted, lower dryer operating efficiencies and very high significant increases in the TBMD and DML as compared to the continuous operation of the dryer for 24 hours. Therefore, the time clock strategy is not recommended for dryer operation.

3.3. Simulation for Jinja: Temperature – Relative Humidity Control Strategy

The second form of strategy tested was selection on the basis of relative humidity and temperature. The dryer can be controlled by a weather station which switches the fan and burner on or off according to ambient conditions, using a controller. The weather conditions are indicated by the air temperature (T_a) and relative humidity (RH_a). Possible strategies were first developed to provide adequate amounts of air at on average good conditions for drying, but for the sake of time and space, three solutions only are discussed here, each being an improvement or refinement on the previous solution in terms of amount of air and drying potential. The following drying strategies were testedin the ISD (in all cases, the burner was designed to heat the air by 5°C):

a. Fans on if RHa> 20% and 10°C< Ta <40°C. Burner on only if RH > 70%.

b. Fans on if 20% <RHa< 95% and 10°C< Ta < 35°C. Burner on only if RH > 75%.

c. Fans on if 20% <RHa< 98% and 10°C< Ta < 37°C. Burner on only if RH > 70%.

Strategy (a) gave the best outputs of DML and drying rate compared to the other strategies (Table **1**). These outputs when compared to the full operation of both fan and burner give reasonable outputs of DML and TBMD but with higher energy consumption and

Table 1: Simulation Outputs for Temperature-Relative Humidity Control Strategy

Day of Year	Drying Strategy	Run Condition			Outputs					
		H (m)	υ_s(m/min)	m_i (% wb)	t (hrs)	D (kg/hr)	E (kJ/kg m.x)	Ɛ (%)	TBMD (%)	DML (%)
210	a	4	10	21	228.6	26.5	3166.1	79.0	1.33	0.4963
210	b	4	10	21	235.2	23.0	2996.5	83.4	1.44	0.6697
210	c	4	10	21	227.4	26.0	3161.3	79.1	1.26	0.5277

lower efficiency. This was mainly due to the high temperature rise of 5°C across the burner that was needed to heat the air, but again confirms that continuous operation gives the best results, provided that the air conditions on average have an adequate drying effect.

3.4. Simulation for Kasese: Time-Clock Control Strategy

Simulation for ISD for Kasese using the weather data for the year 2008 was carried out using the parameters chosen for the case of Jinja ISD simulation. The bed depth/fill height of 4 m, initial moisture content of 21% (w.b.) and air flow rate of 10 m/min had the best outputs for quality and lowest energy consumption for the ISD. These parameters produced a running time of 221 hours, a drying rate of 1.494 kg/hr.m^2, energy consumed per unit area of 100.83 kJ/kg.m^2, efficiency of 126.6%, TBMD of 1.29% and dry matter loss of 0.545%. Hence, a high efficiency, low TBMD, low DML, lower energy consumption and high drying rate were achieved.

Both districts gave reasonable outputs for quality and energy consumption for maize drying standards using the ISD. Comparing the two scenarios, Kasese district had the highest drying rate per unit base area and lowest energy consumption per unit base area per moisture extracted. The final dry weight of maize in the ISD after drying using Jinja and Kasese weather conditions were 7,380.5 kg and 7,454.6 kg respectively. The final dry weights showed the correlation with the quality of the maize after drying. More losses in terms of DML were observed with the ISD for Kasese district at 0.545% but were still within the acceptable range of below 0.8% for DML for maize.

3.5. Cost Analysis Estimations

Cost components affecting the overall cost of grain drying are the energy cost that varies with the amount of moisture removed, the capital cost that is fixed once a dryer is purchased, and the labour cost. Cost estimates were made in this study in order to allow the selection of most cost-effective options.

3.5.1. Assumptions

1) Estimated operating time will be 2 months (1st season) a year (1,440 hours a year).

2) Average drying time while in dryer will be 2 weeks (336 hours)

3) One Australian Dollar = 2500 Ugx (Uganda currency).

4) Heat energy source of the dryer will be LPG, calorific value = 50,208 kJ/kg.

5) Cost of wet maize = 0.096 US$ per kg (240 Ugx per kg)

6) Cost of dry maize = 0.272 US$ per kg (680 Ugx per kg)

7) Cost of LPG per kWhr = 0.148 US$ per kWhr (1kJ = 0.000278 kWhr).

8) Electricity cost = 0.176 US$ per kWh (440 Ugx per unit).

9) Drying capacity, drying time and energy consumption (for both the burner and fan) will be estimated by the ISD simulation program (“ISDryer” version 6.01).

*Ugx is Uganda shillings

A low cost in-store dryer was assumed to be used in this study, comprising of metal corrugated bin walls, fully perforated floor, centralised air duct connected to a centrifugal fan and an LPG burner. The capital cost included all the costs of these features and the total fixed and capital costs were estimated as in Table **2**.

Table 2: Estimated Fixed and Capital Costs for Low Cost ISD

Total Fixed and Capital Costs (FCC)	Rates	Costs (US$)
Purchase price (US$)	8,000.0	
Salvage value in US$ (after 10 yrs)	800.0	
Annual Depreciation	10%	720.0
Insurance	0.5%	22.0
Interest	8%	352.0
Repairs/Maintenance	3%	240.0
Total FCC		1,334.0

From the estimations, a 13.5 tonne (12,816.30 kg of wet maize) ISD is used and the simulation outputs are summarised in Tables **2** and **3**. The annual volume of maize in the dryer was estimated based on the length of the harvesting period in a year. The first harvest season lasts up to 3 months (June/August) in Uganda, and the theoretical seasonal harvesting duration could be up to 2 months (60 days) in a year. The calculation procedures can be seen in the Appendix. The results of cost analysis are shown in Table **4**; all the costs were

Table 3: ISD Operating Variables

Drying Costs	Jinja	Kasese
Cost of electricity (EL)	0.176	0.176
Number of kWhrs used by Fan (EU)	2,185.5	1,770.2
Cost of fuel per kWhr (GU)	0.1480	0.148
Number of kWhrs used by burner (LP)	2,205.2	1,786.2
Hourly wage rate (WL)*	1.2	1.2
Percentage of time spent on dryer (TD) *	20%	20%
Number of labourers needed (n_{lab}) *	12.0	12.0
Time the dryer runs (t_{runs})	300.0	300.0
Time for loading dryer (t_{load}) *	6.0	6.0
Length of harvest period (hrs)	1,440.0	1,440.0
Time for off-loading dryer (t_{unload}) *	6.0	6.0
Number of runs per harvest (n_{runs})	5.7	6.5

* These values were estimated from available literature on dryers

represented in Australian dollars since Uganda is one of the major producers of maize in East Africa.

According to the results, the ISD operating under the Kasese district weather conditions resulted in lower drying time, energy cost and drying cost per kg of dry maize than the ISD in Jinja district. The ISD in Kasese also had more runs per harvest period compared to the ISD in Jinja hence increasing its operating costs but with minimum effect on the drying cost. The average low relative humidity values for Kasese (50.84% to 81.44%) could have contributed to the low energy costs when compared to those of Jinja. Therefore less supplemental heating was needed. The cost of fuel, electricity and labour greatly affects the operating cost of the ISD and hence the drying costs and final profit on the dry maize as seen in Table **4**.

Table 4: Variables used to calculate the Drying Costs and Penalty

Description of Variables		District/Location	
		Jinja	Kasese
kWhrs used:	Burner	2205.2	1786.2
	Fan	2185.5	1770.2
Drying time (t_{dry}) in hrs		241.63	210.06
Initial Moisture content (w_i)		21%	21%
Final Moisture content (w_f)		13.29%	13.39%
Initial wet weight of corn (kg)		12,816.30	12,816.30
DML (%)		0.4470	0.5450
Final weight of corn (kg)		7,380.5	7,454.6
Fuel cost ($)		1,853.0	1,714.29
Electricity cost ($)		2,183.9	2,020.35
Labour cost ($)		4,905.4	5,602.81
Drying cost (OC)		8,942.26	9,337.45
Drying cost per kg ($/kg of dry corn)		0.213	0.193
FCC + OC ($)		10,276.26	10,671.5
Penalty ($/kg dry corn)		0.0004652	0.0005748
Total purchase price ($)		1,230.36	1,230.36
Total selling price ($)		1,998.52	2,016.60
P_{corn} ($/kg dry corn)		0.10408	0.10547
Profit per kg of dry corn ($/kg)		0.0263	0.0507

4. CONCLUSION AND RECOMMENDATIONS

The traditional sun drying of maize is a long and tedious process that can take about two weeks. The maize industry in Uganda is of high national importance and contributes greatly to export earnings and food security, thus the applicability of in-store drying systems to Uganda as an alternative for maize drying and storage is relevant. A fixed size bin (13.5 tonne capacity) was used based on typical farm needs. The predicted drying efficiencies are better than typical values for high temperature dryers, and also will typically have lower capital costs of purchase and construction.

The best operational strategy for drying with an ISD was found to be continuous (24 hr) fan and the burner operation, with the burner needed due to the high relative humidity exhibited in both districts. The average cost of drying a kilogram of dry maize was estimated at around US$0.203/kg for the two districts Jinja and Kasese. The final product after drying had low DML (below 0.6%), indicating a good quality maize.

The profit margins, based on the current price of maize in Uganda, were better for the Kasese district at US$0.0507/kg of maize sold. It was also observed that the drying costs and profit on dry maize were greatly affected by price fluctuations for fuel and electricity, and also the unpredictable prices for maize. Therefore, there is a need to analyse the behaviour of drying costs with increased quality so that it is possible to determine the extra costs with quality improvement. With the use of the ISD, the supply and price of maize may be stabilised. In summary, this study has demonstrated that the ISD may be used in Uganda as an alternative method for maize drying and storage.

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